Geoacoustic Inversion and the Evaluation of Model and Parameter Uncertainties

W.S. Hodgkiss and P. Gerstoft
Marine Physical Laboratory
Scripps Institution of Oceanography
La Jolla, CA 92093-0701
phone: (858) 534-1798 / (858) 534-7768 fax: (858) 822-0665
email: whodgkiss@ucsd.edu / gerstoft@ucsd.edu

Grant Number: N00014-05-1-0264
http://www.mpl.ucsd.edu

LONG-TERM GOALS

The development of new geoacoustic inversion methods, their use in the analysis of shallow water experimental data, and evaluation of geoacoustic model and parameter uncertainties including the mapping of these uncertainties through to system performance uncertainties.

OBJECTIVES

The development of new geoacoustic inversion procedures for use into the kHz frequency regime, the development of methods for estimating the entire posteriori probability densities of the geoacoustic parameters being investigated along with the mapping of these parameter uncertainties through to characterizations of applied interest (e.g. transmission loss), and the demonstration of their use in the analysis of data collected during the Shallow Water 2006 (SW06) experiment.

APPROACH

Geoacoustic inversion involves a number of components:

(a) representation of the ocean environment,

(b) the inversion procedure selected (e.g. genetic algorithm or simulated annealing) including the forward propagation model implemented, and

(c) the estimation of uncertainties associated with the parameter estimates.

The latter is critical to facilitate the mapping of these uncertainties into characterizations of applied interest including the prediction of total system performance.

Substantial experience exists in the application of full-field geoacoustic inversion methods. These have been implemented in a number of geometries (e.g. fixed vertical and horizontal arrays, towed arrays, and sonobuoys) and have been shown to work well at low frequencies (< 1 kHz). The application of these methods at higher frequencies (into the few kHz frequency regime) is at an early stage. New methods are required which are robust to modest geoacoustic heterogeneity (seafloor parameters as well as bathymetry) and temporal fluctuations (sound speed structure, surface waves, and array dynamics).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **Geoacoustic Inversion and the Evaluation of Model and Parameter Uncertainties**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Scripps Institution of Oceanography,Marine Physical Laboratory,La Jolla,CA,92093**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

The reporting of geoacoustic parameter estimates without their associated uncertainties is of limited value. Of substantial greater utility is the complete *a posteriori* probability density (in general, the joint density between all parameters being estimated). One significant benefit of obtaining accurate *a posteriori* densities of the geoacoustic parameters is the potential to map these through to characterizations of applied interest (e.g. transmission loss) in order to quantify those uncertainties as well. The Shallow Water 2006 experiment will take place in July-September 2006 on the outer edge of the New Jersey continental shelf in approximately 80 m deep water. Both narrowband and broadband transmissions (source tows and stations) will be made over a wide range of frequencies (50 Hz – 5 kHz) including detailed measurements of seafloor structure and water column variability. These data will be available for geoacoustic inversion purposes and the investigation of how nuisance parameter uncertainty (e.g. water column sound speed variability) couples into seafloor parameter uncertainty.

WORK COMPLETED

An approach has been developed for incorporating the total uncertainty in observations into the uncertainty of geoacoustic parameter estimates [3]. The total error variance includes both ambient noise as well as modeling errors. By including an estimate of the total error variance in the inversion process, more realistic estimates of geoacoustic parameter uncertainties are obtained.

RESULTS

Previously, geoacoustic inversion results from the ASIAEX East China Sea experiment were reported for low frequency source tow transmissions (195, 295, and 395 Hz) [1]. Subsequently, these results were used in an initial demonstration of an approach for mapping uncertainty in the geoacoustic parameter estimates into uncertainty in predicted transmission loss [2].

Quantifying uncertainty for geoacoustic parameter estimates requires estimation of the uncertainties in the data due to both ambient noise as well as modeling errors with the latter accounting for simplistic assumptions about seafloor structure, water column variability, range dependencies, etc. [3]. Both of these combine in a total error variance which describes the data uncertainty. Data analyzed in [1] will be used as an illustration.

The observed data corresponds to a source position approximately 48 m deep and 1.7 km away from a 16 element vertical line array deployed in 105 m deep water. A total of 13 parameters (geoacoustic, geometric, and water column sound speed) were estimated in the original inversion which made use of a genetic algorithm based global optimization procedure [1]. Here we investigate the posterior probability densities (PPDs) of the following 5 model parameters via exhaustive search: (1) water depth, (2) sediment sound speed, (3) basement sound speed increase, (4) sediment thickness, and (5) sediment attenuation, with all other parameters fixed at the values estimated in the original inversion. Just two frequencies are included (195 and 395 Hz). Thus, the joint PPDs of 7 parameters are being investigated – the 5 model parameters plus the error variances at the two frequencies.

Fig. 1 shows the 1-D (along the diagonal) and 2-D (contour subplots in the upper triangle) marginal PPDs of the geoacoustic parameters as well as the error variances for the two frequencies. In each contour plot, the gray-scale level from darkest to lightest represents the 50%, 75%, and 95% highest posterior density (HPD). In the 1-D marginals, the horizontal bar shows the 95% HPD interval.

Fig. 2 shows the marginal PPDs of the error variances. The dotted line represents the ambient noise level estimated directly from the data and the dashed line corresponds to the maximum likelihood (ML) estimate of the total error variance. Importantly, the marginal distributions of the error variances show that the ambient noise value underestimate significantly the total error. In the experimental data with high SNR, the modeling error in the parameterized environment is the dominant source of error in the estimation procedure.

Lastly, Fig. 3 compares the marginal PPDs for the 5 model parameters using different error variance estimates. The marginal PPDs of the model parameters using the ambient noise variance (dotted lines) yield too optimistic an uncertainty estimate. The marginal PPDs based on the ML estimate of the error variance (dashed lines) are similar to the ones obtained by the full Bayesian approach (solid lines) which incorporate the entire PPD of the error variances. Both of these yield more conservative uncertainty estimates for the model parameters.

IMPACT / APPLICATIONS

Geoacoustic inversion techniques are of general interest for the estimation of waveguide parameters thus facilitating system performance prediction in shallow water. Natural transition paths for these results will be SPAWAR (PMW-155) and NAVSEA (ASTO).

RELATED PROJECTS

This project is one of several sponsored by ONR Code 321OA to participate in the Shallow Water 2006 experiment.

PUBLICATIONS

[1] C-F. Huang and W.S. Hodgkiss, "Matched field geoacoustic inversion of low frequency source tow data from the ASIAEX East China Sea experiment," IEEE J. Oceanic Engr. 29: 952-963 (2004). [published, refereed]

[2] P. Gerstoft, C-F. Huang, and W.S. Hodgkiss, “Estimation of transmission loss in the presence of geoacoustic inversion uncertainty,” IEEE J. Oceanic Engr. (in press, 2005). [in press, refereed]

[3] C-F. Huang, P. Gerstoft, and W.S. Hodgkiss, “Uncertainty analysis in matched-field geoacoustic inversions,” J. Acoust. Soc. Am. (in press, 2005). [in press, refereed]

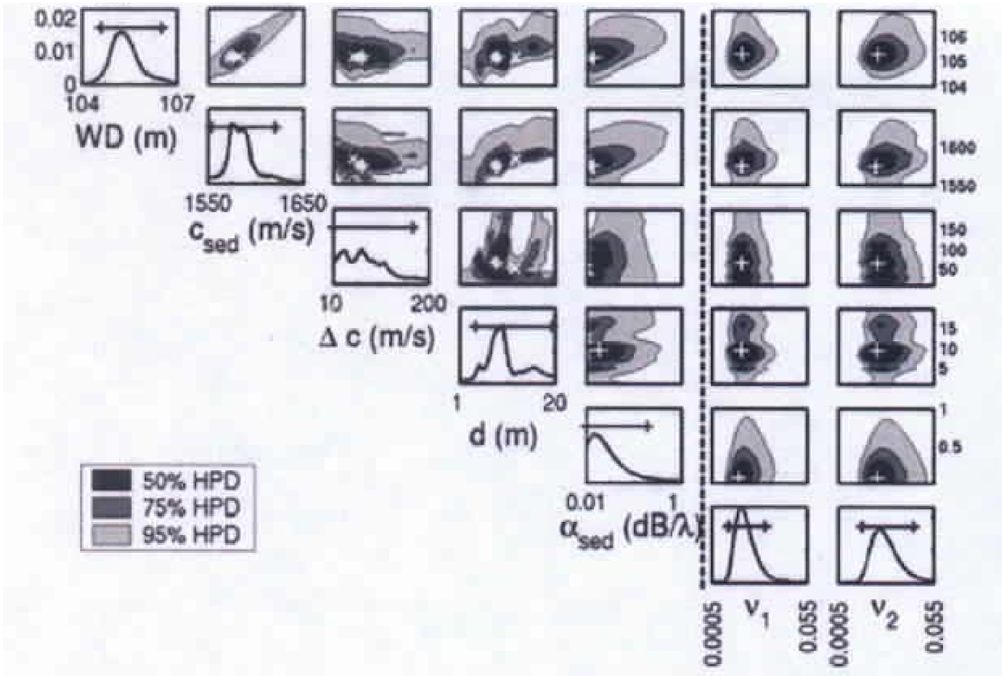

Figure 1. 1-D and 2-D marginal PPDs of the geoacoustic parameters as well as the error variances for the frequencies 195 and 395 Hz.

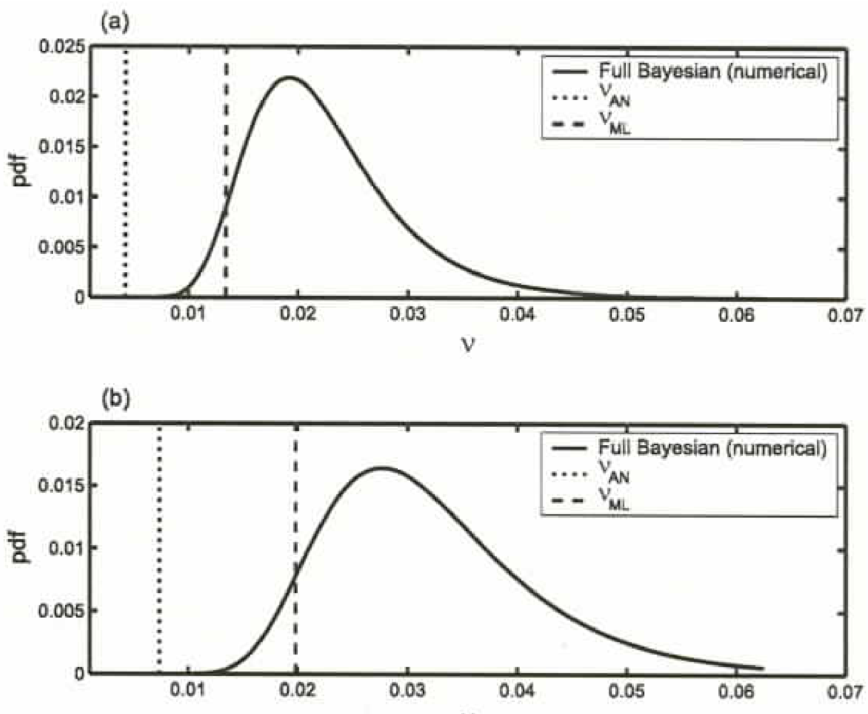

Figure 2. Marginal PPDs of the error variances. (a) f = 195 Hz and (b) f = 395 Hz. The vertical lines show the different estimates of the error variances and illustrate that the ambient noise estimate underestimates significantly the total error variance.

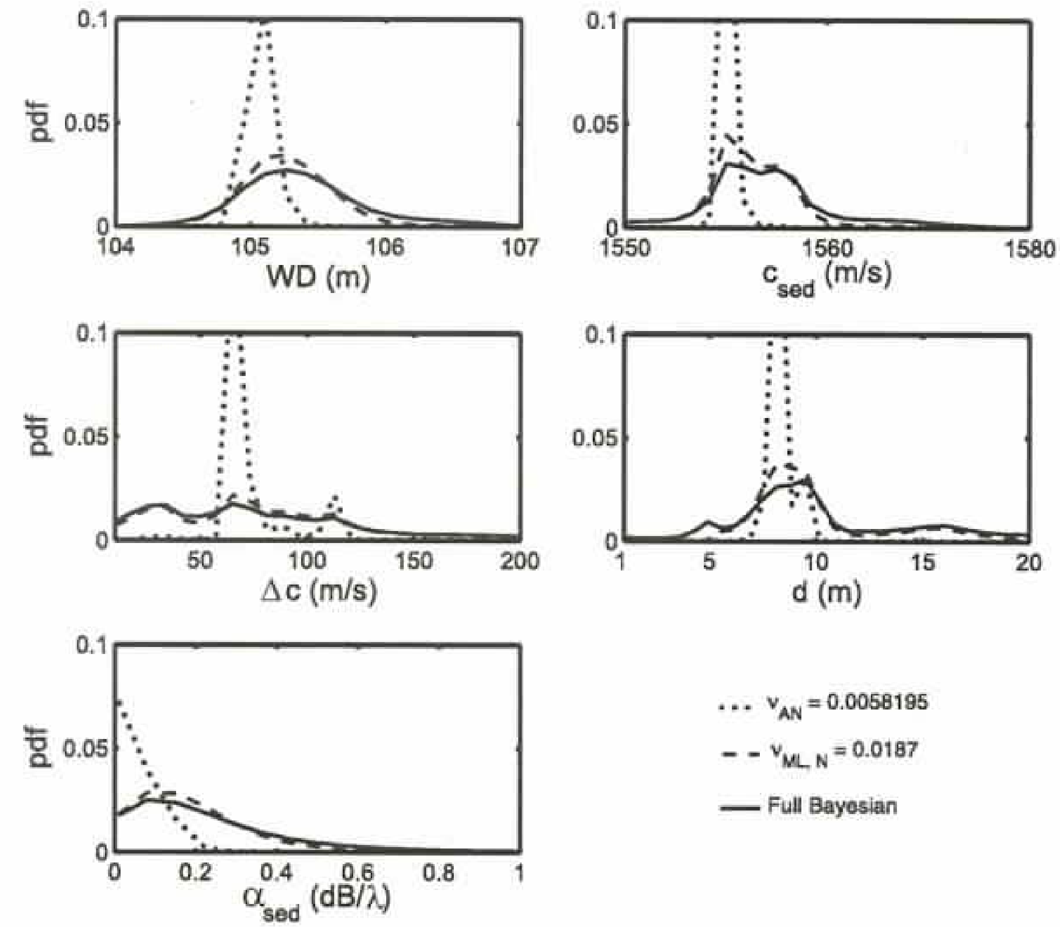

Figure 3. Comparison of the marginal PPDs for the 5 model parameters using different error variance estimates. The marginal PPDs using the ambient noise variance (dotted lines) yield too optimistic an uncertainty estimate.